Chapter 3. Seasonal Distributions of $PM_{2.5}$ Aerosol Mass

The seasonality of aerosol concentrations can be significant depending on species and region and is a function of the source emissions, meteorological parameters, and local and long-range transport. Examining aerosol concentrations on a regional basis, rather than a site-specific basis, can lead to insights regarding air quality issues on regional scales. In this chapter, the differences in the regional seasonal patterns of major aerosol species and their contributions to reconstructed fine mass are examined for rural and urban regions.

IMPROVE and CSN data were aggregated according to semi-empirically defined regions. When a specific region is used in this report, it refers to an IMPROVE or CSN region as defined in Figure 1.2 or Figure 1.15, respectively (Chapter 1), not a commonly-used geographical region. For example, the IMPROVE "Northwest" region refers to a specific group of IMPROVE sites, not to the geographical area typically considered as "northwestern United States". There are 36 IMPROVE regions, 29 of which are rural, four that are urban (including both long-term urban sites and urban quality assurance sites), and three that are international sites (see Table 1.1 in Chapter 1). Some rural regions may have only one site (e.g., Death Valley, Lone Peak, Virgin Islands). The IMPROVE regions were defined based on site location and the seasonal distribution of aerosol concentrations for major species (e.g., Malm et al., 2000; Debell et al., 2006; Hand et al., 2011). The variability in the species composition between sites in a given region were not investigated, nor were differences in elevation accounted for.

A similar semi-empirical method for grouping sites was used for the CSN network, resulting in 29 regions (Hand et al., 2011; Hand et al., 2012). Eleven regions had only one site per region. A list of the 136 sites that met the completeness criteria (outlined in Chapter 2) is provided in Table 1.8 in Chapter 1, including site location, region, and setting (urban, suburban, or rural).

The monthly and annual mean concentrations of $PM_{2.5}$ ammonium sulfate (AS), ammonium nitrate (AN), particulate organic matter (POM), elemental carbon (EC), fine dust (FD), sea salt (SS), coarse mass (CM), and reconstructed fine mass (RCFM) were analyzed. The fractional contribution of an individual species mass to RCFM was also determined. Evaluation of the seasonal distributions of both absolute and relative concentrations highlights the relative importance of each species to the $PM_{2.5}$ mass budget throughout the year.

The monthly mean IMPROVE and CSN regional data are presented as stacked bar charts. Monthly mean concentrations are depicted with the first letter of the month followed by an "A" for annual mean. Stacked bar charts for monthly mean concentrations are grouped into figures corresponding to three sections of the country: eastern, northwestern, and southwestern United States. Stacked bar charts for monthly mean mass fractions are also provided. Scales vary for each regional bar plot. The following sections are organized by species and include discussions for both IMPROVE and CSN.

3.1 $PM_{2.5}$ AMMONIUM SULFATE

3.1.1 IMPROVE

The majority of sulfate in the atmosphere is produced through chemical reactions of sulfur dioxide (SO_2). Anthropogenic sources of SO_2 include industrial activities, such as coal and diesel fuel combustion, and emissions of SO_2 are highest in the eastern United States. Elevated relative humidity or other aqueous pathways create the most efficient conditions for sulfate production and, along with transport, lead to regional impacts of sulfate aerosols on $PM_{2.5}$. The maximum 2016–2019 regional monthly mean AS concentration of 2.77 $\mu g\ m^{-3}$ occurred in Hawaii in March due to volcanic emissions of SO_2. The maximum CONUS (continental United States) monthly mean concentration occurred in the Ohio River Valley region in July (2.25 $\mu g\ m^{-3}$), followed by the Midsouth region in September (2.10 $\mu g\ m^{-3}$). The minimum regional monthly mean AS concentration occurred in both the Northwest and Oregon/Northern California regions in January (0.13 $\mu g\ m^{-3}$). In most of the regions in the eastern United States, regional mean AS concentrations rarely exceeded 2 $\mu g\ m^{-3}$ year round (Figure 3.1.1). Monthly mean AS in regions farther north, such as the Boundary Waters and Northeast regions, were 1 $\mu g\ m^{-3}$ or less year round. In addition, the monthly variability of AS was flat, with a small increase in summer months in some regions (e.g., MidSouth and East Coast). Monthly mean concentrations in regions in the northwestern United States were lower than in the eastern United States (typically <1 $\mu g\ m^{-3}$) and had little seasonal variability (see Figure 3.1.2). The highest mean AS concentrations in regions in the northwestern United States occurred in the Northern Great Plains and Columbia River Gorge regions, where concentrations approached 1 $\mu g\ m^{-3}$. AS concentrations in the regions of the southwestern United States (Figure 3.1.3) were generally <2 $\mu g\ m^{-3}$ and demonstrated more of a summer peak (e.g., Southern California, Southern Arizona, and West Texas regions). Low monthly mean concentrations (<1 $\mu g\ m^{-3}$) were observed in the Great Basin, Colorado Plateau, and Central Rockies regions. In the Hawaii region, monthly mean AS concentrations were >1 $\mu g\ m^{-3}$ for most months of the year.

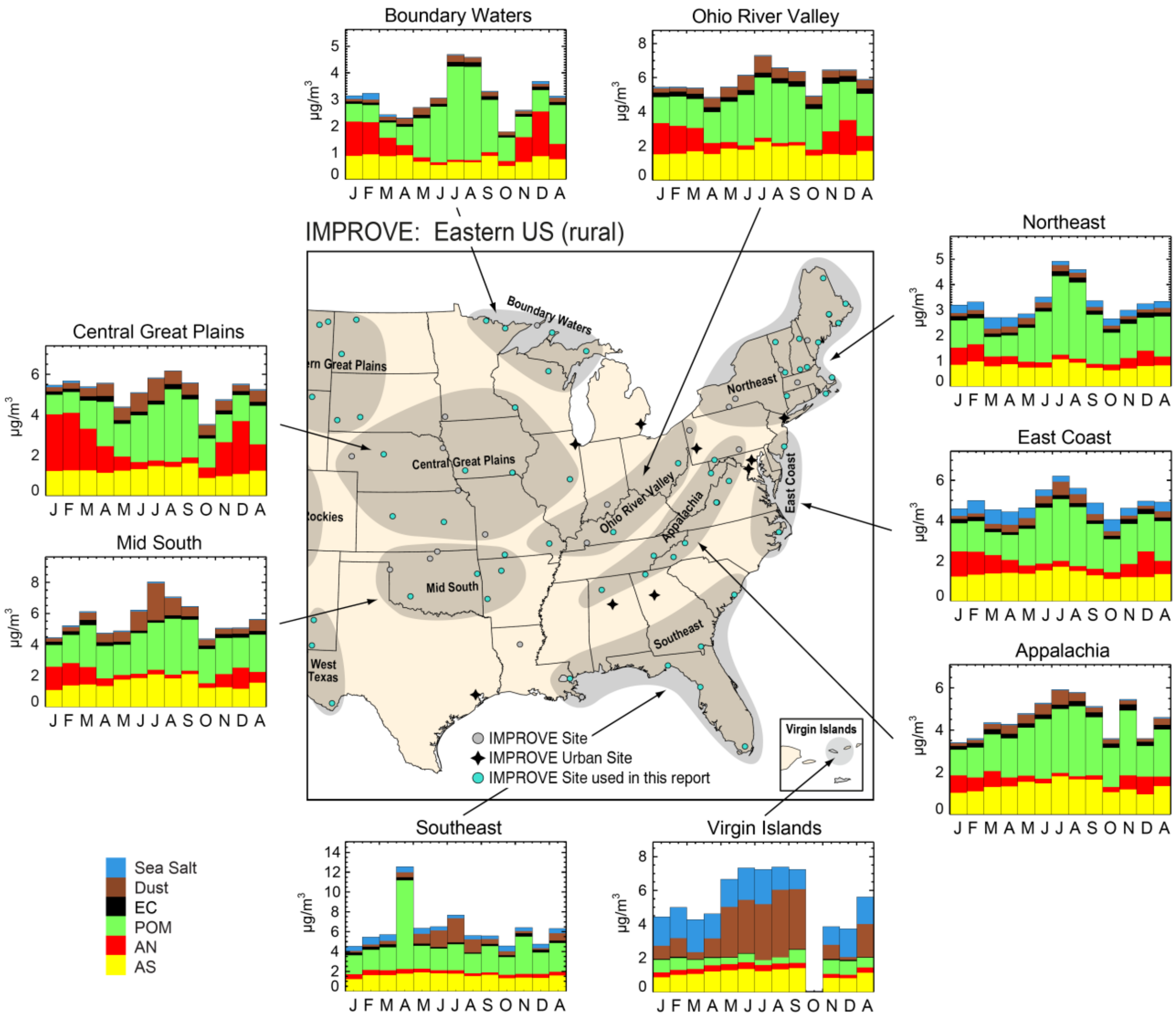

Figure 3.1.1. IMPROVE 2016–2019 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the eastern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as blue dots.

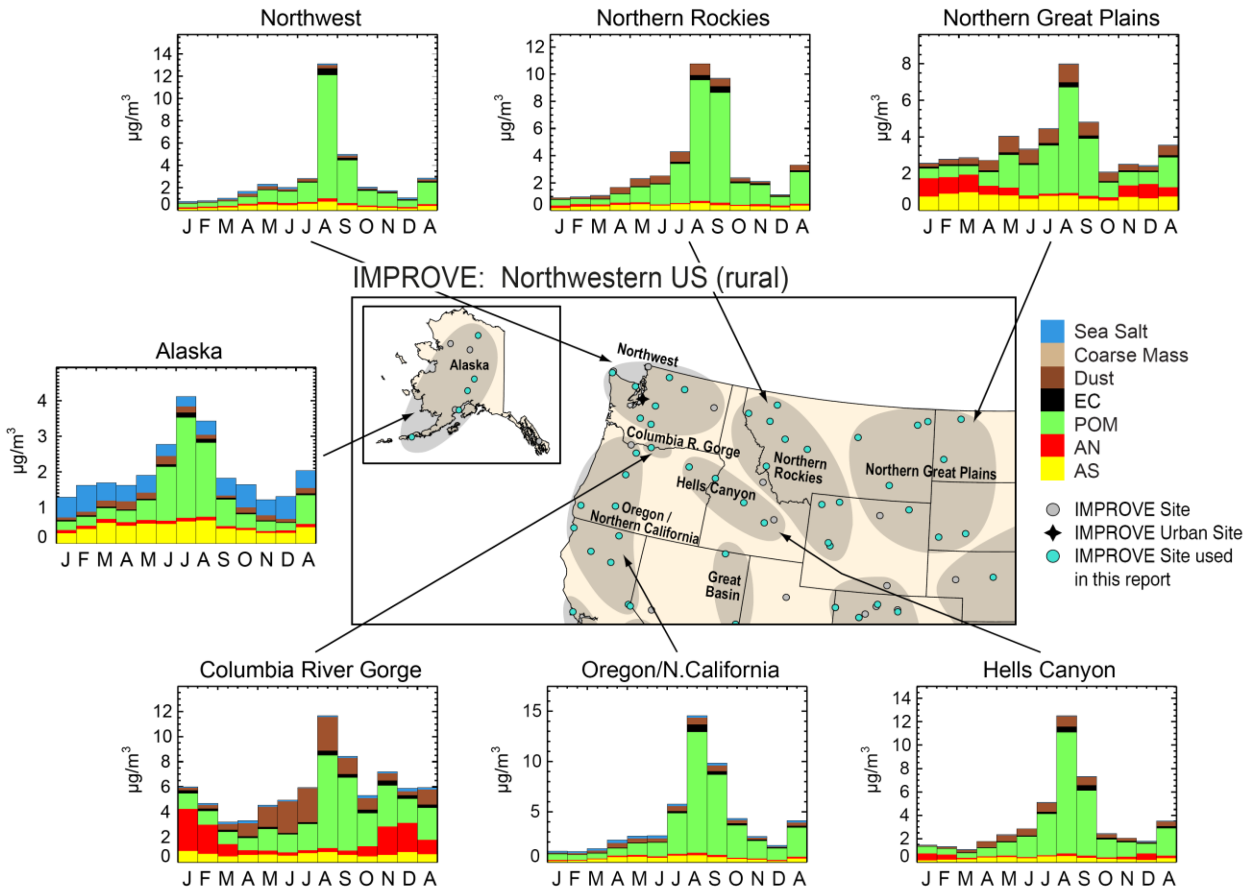

Figure 3.1.2. IMPROVE 2016–2019 regional monthly mean $PM_{2.5}$ mass concentrations (μg m^{-3}) for the northwestern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as blue dots.

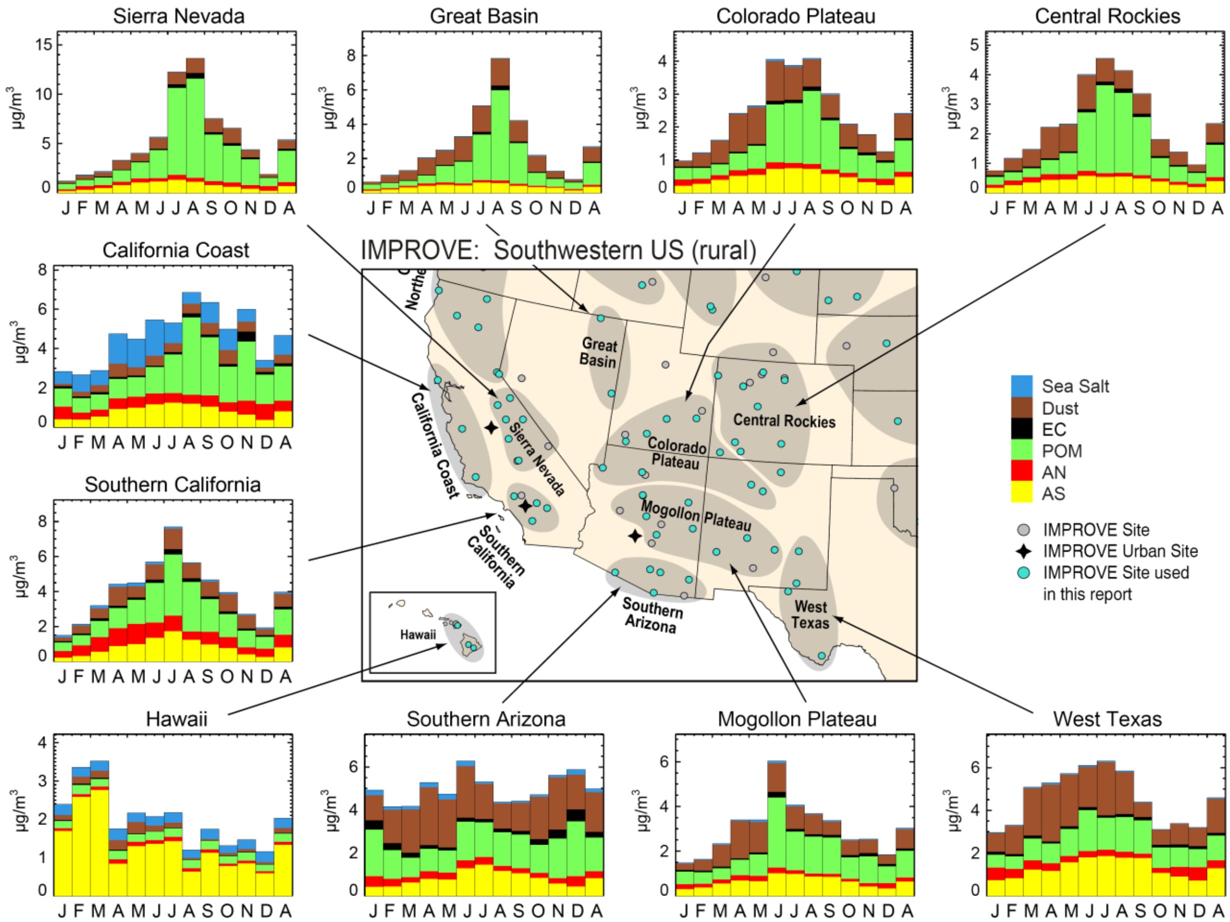

Figure 3.1.3. IMPROVE 2016–2019 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the southwestern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as blue dots.

The maximum IMPROVE regional monthly mean fractional contributions of AS to RCFM of 0.787 occurred in the Hawaii region in March, where maximum AS concentrations also occurred. The Hawaii region had monthly mean contributions from over 0.5 to near 0.8 year round. The minimum contribution of 0.038 occurred in the Northern Rockies region in September. Low contributions also occurred in August in the Hells Canyon region (0.044) and the Oregon/Northern California region (0.047). The CONUS regional mean maximum contributions occurred in the West Texas region (0.404) in September and in the Boundary Waters region (0.392) in April. Regions in the eastern United States typically had AS contributions between 0.2 and 0.3 year round (Figure 3.1.4) with no strong seasonal maxima, except in the Boundary Waters region, which experienced higher contributions in spring and fall. In the northwestern United States, contributions from AS to RCFM of around 0.2 occurred during spring months for many regions. (Figure 3.1.5). Much of the seasonal variability in AS contributions in the northwestern United States was due to the contributions of other species, such as POM in summer. In the southwestern United States (Figure 3.1.6), the regional mean contributions were around 0.20 or less. Seasonal variability of regions farther north indicated larger contributions in spring and fall (e.g., Sierra Nevada and Great Basin regions), in part due to strong contributions of POM in summer. Farther south, seasonal maxima occurred in summer in the Southern Arizona region, but other regions showed little seasonal variability in AS contributions (e.g., Mogollon Plateau and Colorado Plateau regions).

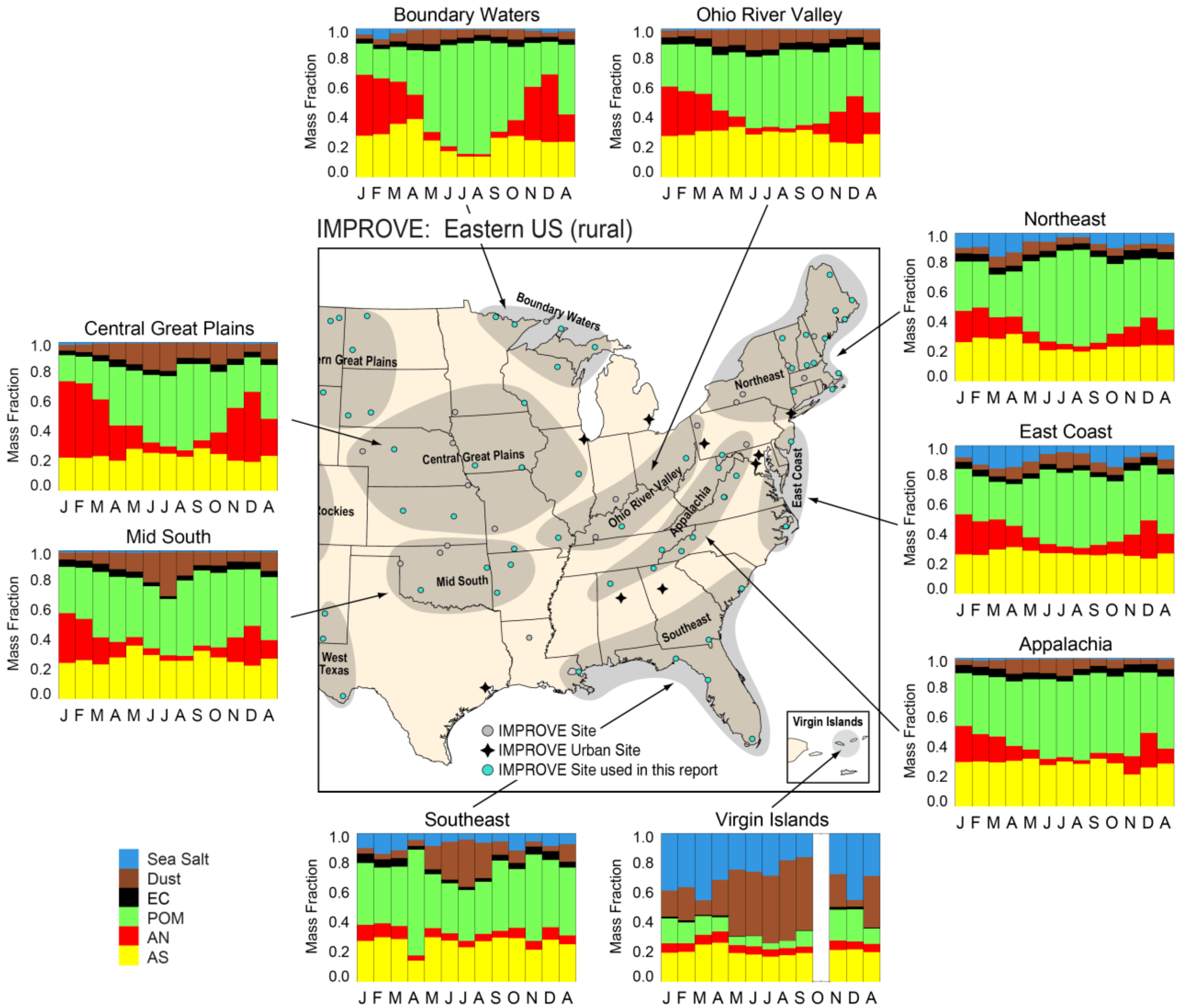

Figure 3.1.4. IMPROVE 2016–2019 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the eastern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as blue dots.

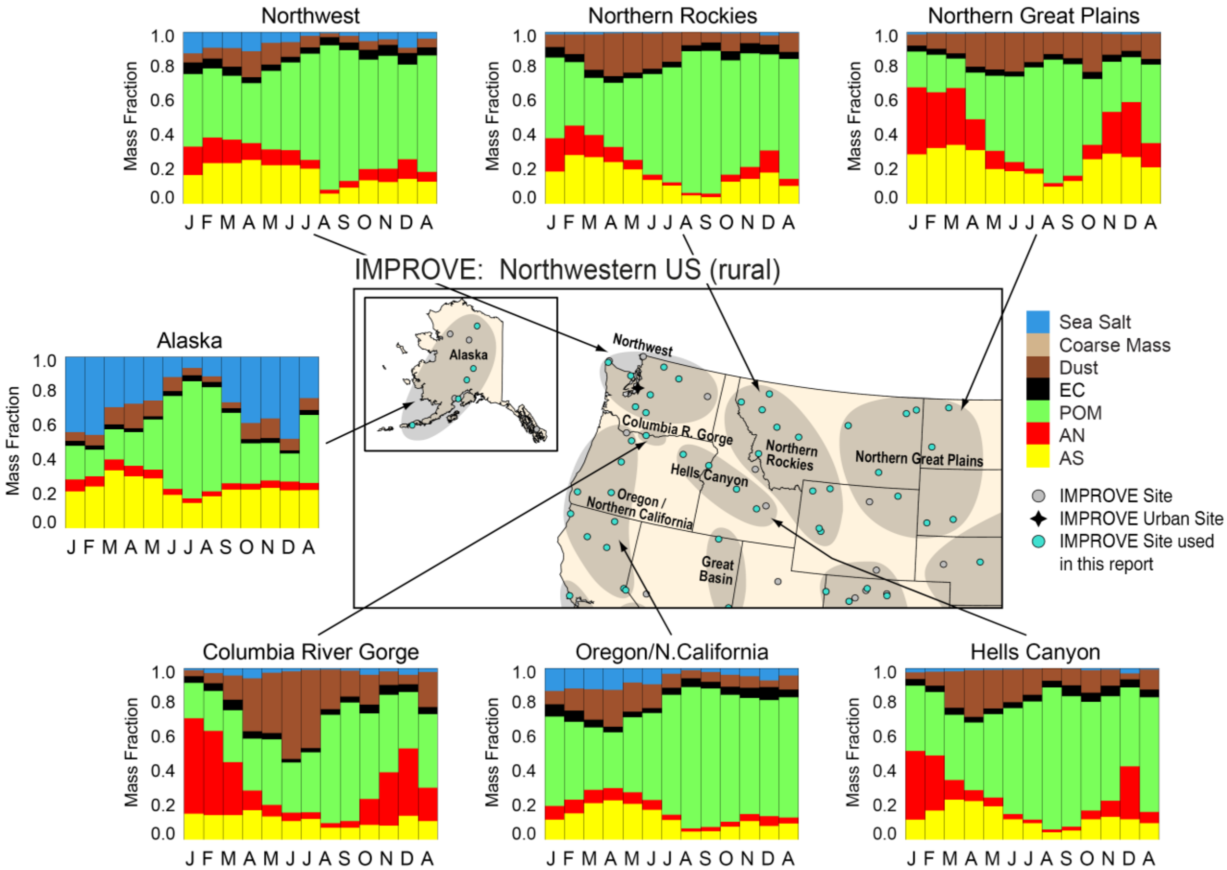

Figure 3.1.5. IMPROVE 2016–2019 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the northwestern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as blue dots.

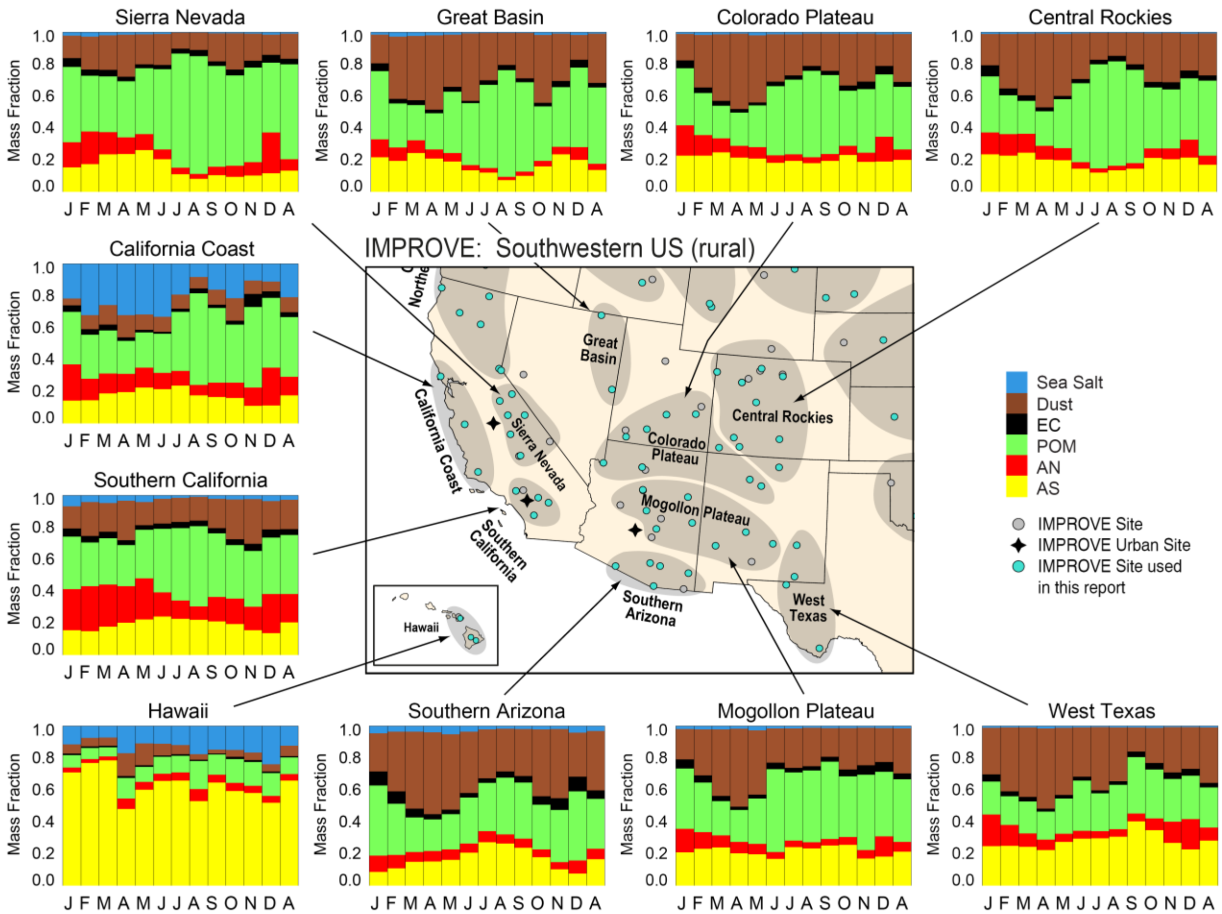

Figure 3.1.6. IMPROVE 2016–2019 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the southwestern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as blue dots.

3.1.2 CSN

The CSN maximum regional monthly mean AS concentration was 4.76 µg m^{-3} in the Alaska region in January, followed by the CONUS maximum of 3.61 µg m^{-3} in the Los Angeles region in July. The regional minimum mean AS concentration (0.29 µg m^{-3}) occurred in the Northwest region in March. Similar to the IMPROVE regions, in CSN regions AS monthly mean concentrations in the eastern United States rarely reached above 2 µg m^{-3} (see Figure 3.1.7). The similarity in seasonal patterns of AS concentrations in the eastern United States pointed to regional sources of AS that impact urban and rural regions alike (compare Figures 3.1.1 and 3.1.7). In addition, the seasonal variability was quite low, with mostly flat monthly mean concentrations year round. Monthly mean AS concentrations were generally quite low (<1.5 µg m^{-3}) for regions in the northwestern United States (Figure 3.1.8) and were seasonally flat, similar to IMPROVE monthly mean concentrations (see Figure 3.1.2). The exception was the Alaska region, with maximum monthly mean concentrations during cold months. The regional monthly mean AS concentrations in the southwestern United States were generally low (<2.0 µg m^{-3}) in most regions but with more seasonal variability than in the eastern United States (Figure 3.1.9). Summer maxima were observed for many regions, such as in the Phoenix/Tucson, Albuquerque, Las Vegas, and West Texas regions. The strongest seasonal variability occurred in the Los

Angeles and San Diego regions with summer maxima. These patterns also occurred for IMPROVE regions. The Hawaii region experienced some seasonal variability with winter maxima.

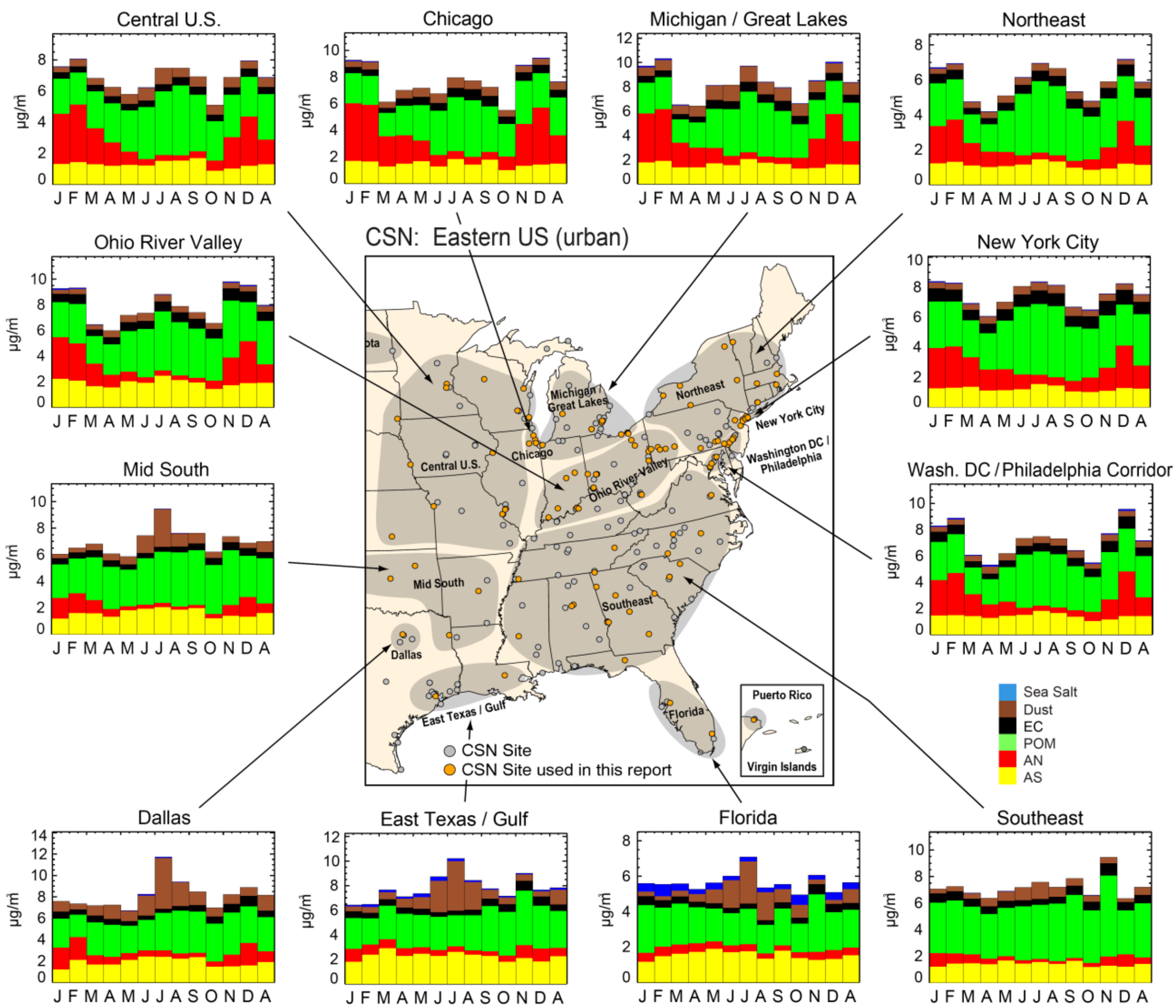

Figure 3.1.7. CSN 2016–2019 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the eastern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as orange dots.

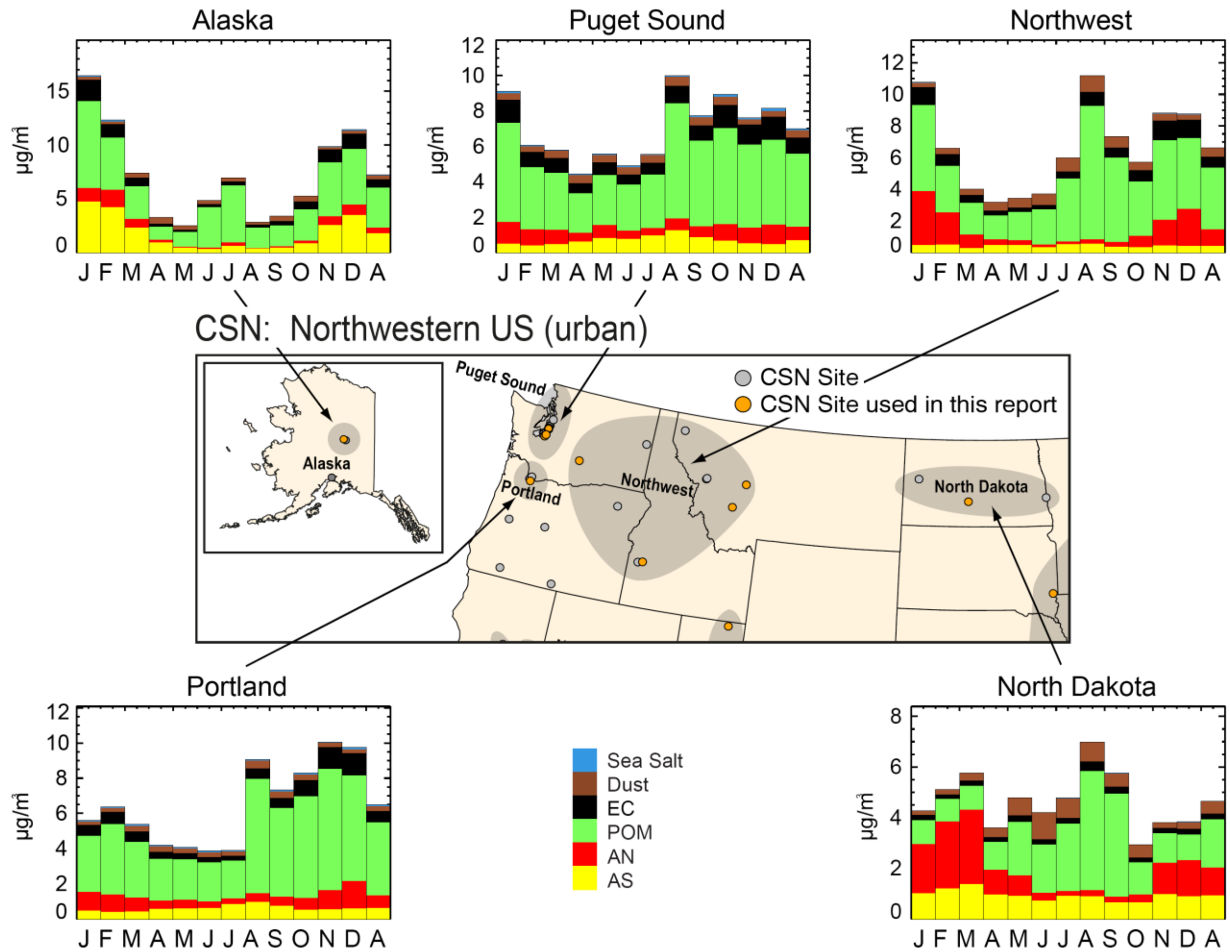

Figure 3.1.8. CSN 2016–2019 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the northwestern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as orange dots.

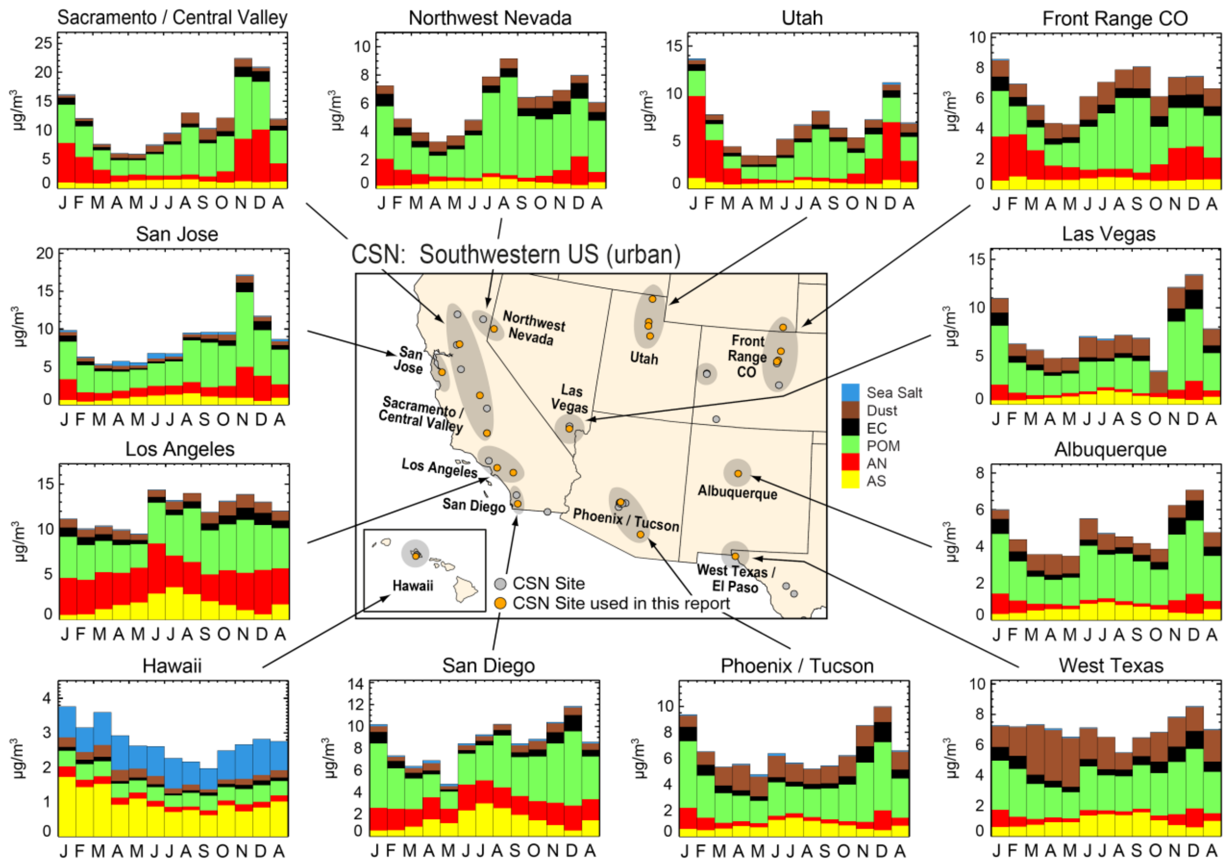

Figure 3.1.9. CSN 2016–2019 regional monthly mean $PM_{2.5}$ mass concentrations (µg m^{-3}) for the northwestern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as orange dots.

The CSN AS regional fractional contribution to RCFM ranged from 0.027 in the Northwest Nevada region in January to 0.460 in the Hawaii region in January and 0.381 in the CONUS region of East Texas/Gulf in March. With the exception of the East Texas/Gulf and Florida regions, the monthly mean AS fractional contribution to RCFM was rarely above 0.3 in regions across the United States. In many regions in the eastern United States, the fractional contribution did not vary much seasonally, averaging around 0.2, with the exception of the Midsouth region that demonstrated a small summer peak that reached ~ 0.3 (Figure 3.1.10). Generally, regions in the northwestern United States had lower AS contributions, typically <0.2 (Figure 3.1.11). The Alaska region had higher contributions in cold months, but CONUS regions displayed different seasonal variability, with spring maxima in the Puget Sound and Northwest regions and summer maxima in the Portland region. More seasonal variability was observed in regions in the southwestern United States (Figure 3.1.12), with summer maxima in urban regions farther south, such as many of the regions in California, as well as the Phoenix/Tucson region in Arizona. The Sacramento/Central Valley and Northwest Nevada regions experienced spring maxima. Like the Northwest region, contributions of AS to RCFM were around 0.2 or less. Contributions in the Hawaii region were near 0.4 or less but with low seasonal variability.

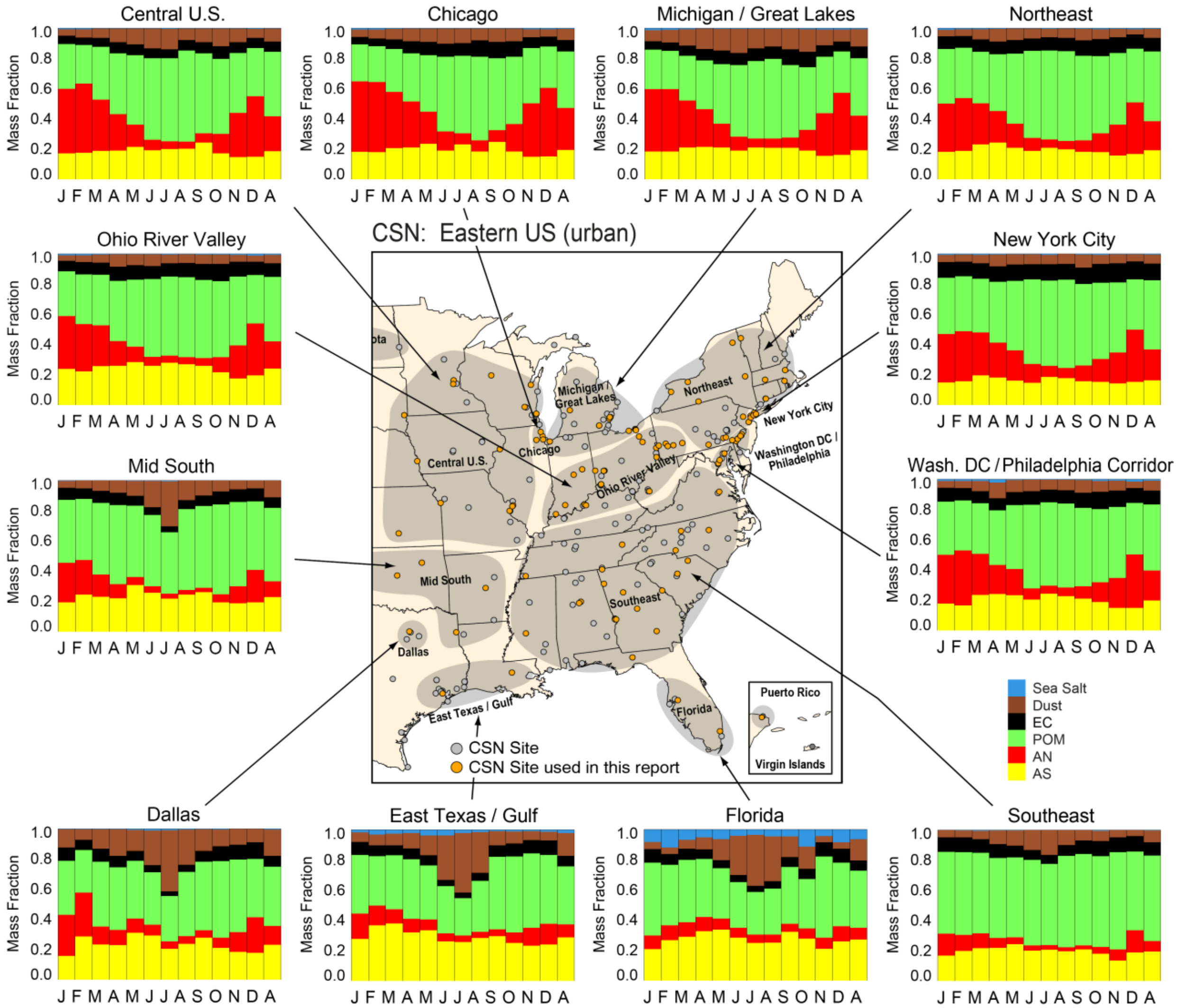

Figure 3.1.10. CSN 2016–2019 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the eastern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as orange dots.

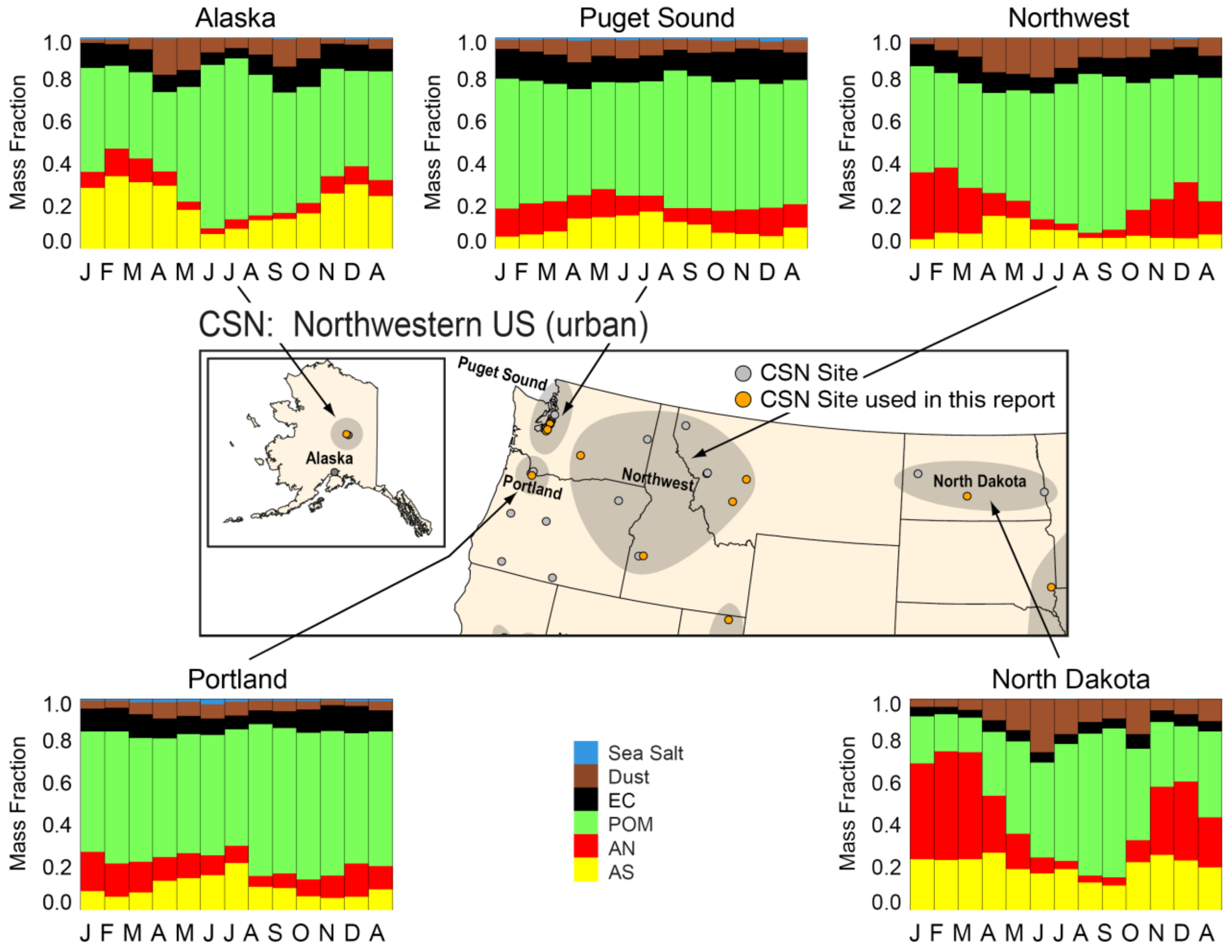

Figure 3.1.11. CSN 2016–2019 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the northwestern United States. Letters on the x-axis correspond to month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as orange dots.

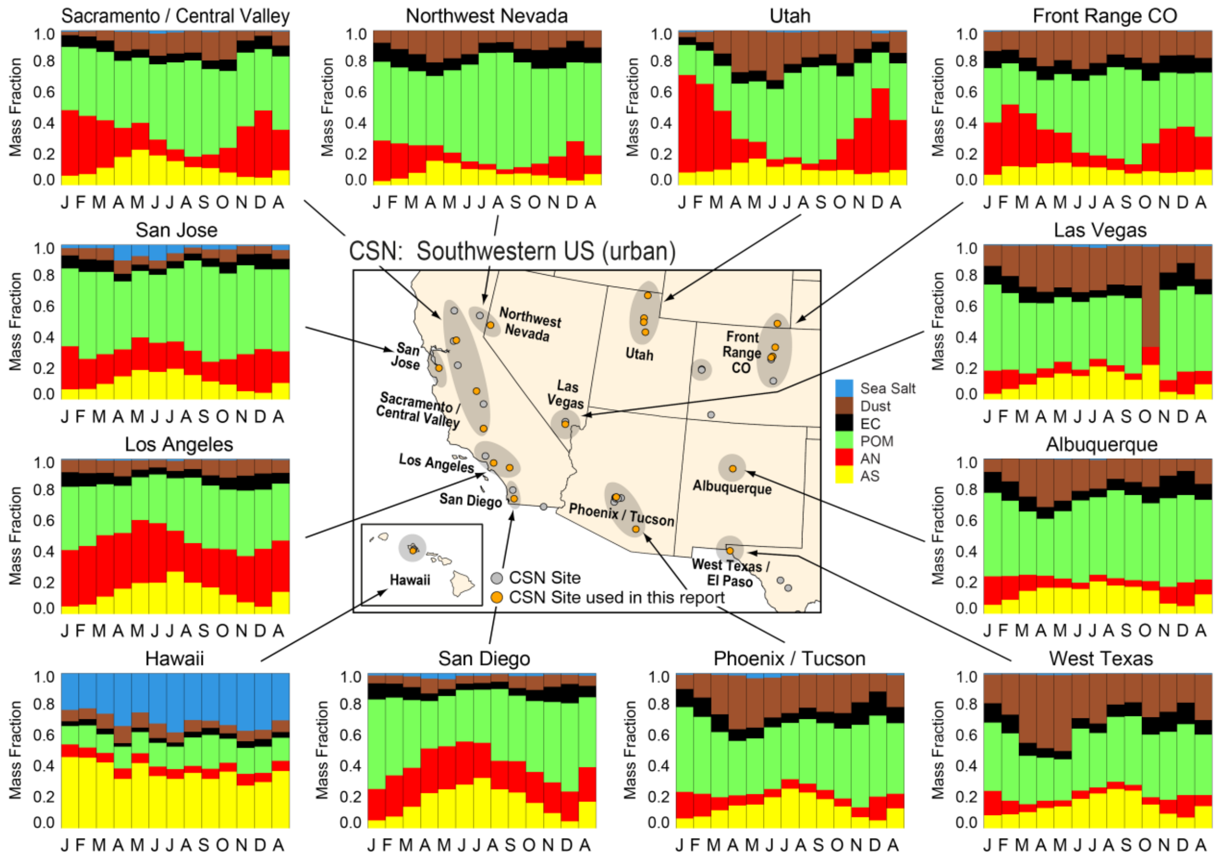

Figure 3.1.12. CSN 2016–2019 regional monthly mean $PM_{2.5}$ reconstructed fine mass fractions for the southwestern United States. Letters on the x-axis correspond to the month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as orange dots.

3.2 $PM_{2.5}$ AMMONIUM NITRATE

3.2.1 IMPROVE

Recall from Chapter 2 that AN forms from the reversible reaction of gas-phase ammonia and nitric acid, a form of oxidized nitrogen. Sources of oxidized nitrogen include combustion of fossil fuels and biomass. Sources of ammonia include agricultural activities, mobile sources, and natural emissions. Lower temperatures and higher relative humidity favor particulate AN. Regions with oxidized nitrogen and ammonia emissions, as well as locations and seasons that favor AN formation, will likely be associated with higher AN concentrations. The IMPROVE 2016–2019 regional maximum monthly mean ammonium nitrate (AN) mass concentration (3.35 $\mu g\ m^{-3}$) occurred in the Columbia River Gorge region in January. A minimum regional monthly mean concentration of 0.05 $\mu g\ m^{-3}$ was observed both in the Alaska region in October and the Hawaii region in December. The minimum CONUS monthly mean concentration of 0.06 $\mu g\ m^{-3}$ occurred in the Great Basin region in November. In the eastern United States, the highest AN monthly mean concentrations occurred during winter months in the Central Great Plains region, near 3 $\mu g\ m^{-3}$ (Figure 3.1.1). Along with the Central Great Plains region, winter monthly mean concentrations were generally higher for regions farther north, such as the Boundary Waters and

Ohio River Valley regions, with mean concentrations nearing 2 $\mu g\ m^{-3}$. Farther south, such as the Southeast and Appalachia regions, mean concentrations were much lower (<1 $\mu g\ m^{-3}$ year round). In the northwestern United States, the highest monthly mean concentrations occurred during winter months in the Columbia River Gorge and Northern Great Plains regions (Figure 3.1.2). Other regions in the northwestern United States experienced relatively low concentrations year round (<0.3 $\mu g\ m^{-3}$). Regions in the southwestern United States also had low concentrations (Figure 3.1.3). The exceptions were the California Coast and Southern California regions, where concentrations were higher (<1 $\mu g\ m^{-3}$). Unlike regions in the eastern United States, regions in the northwestern and southwestern United States had low monthly variability, and, interestingly, the AN monthly mean concentrations in the Southern California region peaked in spring.

Rural IMPROVE monthly mean mass fractions for AN ranged from 0.014 in the Northern Rockies region in August to 0.557 in the Columbia River Gorge region in January. In regions farther north in the eastern United States, mass fractions reached 0.5 or higher during winter, such as in the Boundary Waters and Central Great Plains regions (Figure 3.1.4). Regions such as the East Coast and Appalachia regions also had higher mass fractions in the winter, from 0.2 to 0.3. The Southeast region experienced the lowest mass fractions, near 0.1 or less. The highest AN monthly mean mass fractions in the northwestern United States occurred in the Columbia River Gorge, Northern Great Plains, and Hells Canyon regions, with mass fractions greater than 0.4 in winter (Figure 3.1.5). The mass fractions in the Northwest, Northern Rockies, and the Oregon/Northern California regions were <0.2. Across the southwestern United States, most regions experienced relatively low AN monthly mean mass fractions, typically <0.2 (Figure 3.1.6). The exception was the Southern California region, where mass fractions were closer to 0.25–0.3 and higher during spring months.

3.2.2 CSN

The maximum CSN regional monthly mean concentration (9.10 $\mu g\ m^{-3}$) occurred in the Sacramento/Central Valley region in December, and the minimum concentration occurred in the Alaska (0.07 $\mu g\ m^{-3}$) and Hawaii (0.10 $\mu g\ m^{-3}$) regions, both in August, and in the CONUS region of Albuquerque in September (0.17 $\mu g\ m^{-3}$). In the eastern United States, a strong seasonal pattern was observed with peaks in winter months, especially for regions farther north (Figure 3.1.7). High concentrations (~4 $\mu g\ m^{-3}$) occurred in winter months in the Central U.S. and Michigan/Great Lake regions. Concentrations decreased for regions farther south, such as the East Texas/Gulf, Florida, and Southeast regions, with lower monthly variability. A similar spatial pattern was observed for IMPROVE regions. Concentrations were generally lower for regions in the northwestern United States (Figure 3.1.8). The Northwest and North Dakota regions had the highest monthly mean concentrations near 3 $\mu g\ m^{-3}$ during winter months. Farther west, concentrations decreased, but a seasonal pattern with higher winter concentrations was observed. Regions in the southwestern United States experienced the highest monthly mean concentrations (see Figure 3.1.9). The maximum monthly concentrations in Sacramento/Central Valley region were only slightly higher than those observed in the Utah region in December (8.62 $\mu g\ m^{-3}$). Mean concentrations decreased in regions farther south, such as in the Las Vegas, Albuquerque, West Texas, and Phoenix/Tucson regions, although maxima still occurred in winter months. In contrast, regions in southern California, such as Los Angeles and San Diego, experienced higher concentrations year round.

CSN regional monthly mean AN fractional contributions to RCFM ranged from 0.024 in both the Alaska and the Northwest regions in August to 0.631 in the Utah region in January. In the eastern United States, the contribution of AN to RCFM was considerable (near 0.5) in regions farther north, such as the Central U.S., Chicago, and the Michigan/Great Lakes regions (Figure 3.1.10). Similar to IMPROVE regions in the eastern United States, contributions decreased farther south, such as the Southeast, Florida, and East Texas/Gulf regions (<0.15). In the northwestern United States, the contributions reached 0.5 in the North Dakota region and 0.3 in the Northwest region, both during winter months (Figure 3.1.11). Other regions in the northwestern United States had lower contributions and lower monthly variability. Strong seasonal patterns in the contributions of AN to RCFM were observed in the Utah and Front Range CO regions in the southwestern United States (Figure 3.1.12). However, farther south, the contributions decreased as did the monthly variability. In the San Diego, Los Angeles, and San Jose regions, the contributions ranged between ~0.2–0.4 and were nearly constant year round. Monthly mean contributions in the Hawaii region were <0.1 year round.

3.3 $PM_{2.5}$ PARTICULATE ORGANIC MATTER

3.3.1 IMPROVE

The sources of POM in the atmosphere are both primary emissions and secondary formation. Primary emissions are emitted directly into the atmosphere and include particles from combustion of fossil fuels and biomass. Secondary organic aerosols form from the oxidation of gas-phase organic precursors from both anthropogenic and biogenic sources. IMPROVE 2016–2019 regional monthly mean POM concentrations ranged from 0.17 $\mu g\ m^{-3}$ in the Hawaii region in December and 0.27 $\mu g\ m^{-3}$ in both of the CONUS regions of the Central Rockies and Great Basin, both in January, to a maximum monthly mean POM concentration of 12.0 $\mu g\ m^{-3}$ in the Oregon/Northern California region in August. In the eastern United States, POM concentrations were highly seasonal, with peaks in summer months (Figure 3.1.1). During July and August, concentrations reached over 3 $\mu g\ m^{-3}$ in most regions, such as the Boundary Waters, Ohio River Valley, Central Great Plains, Northeast, Appalachia, and East Coast regions. The strong peak in POM in April in the Southeast region was due to the influence of biomass smoke. The Virgin Islands region had relatively low concentrations (<1 $\mu g\ m^{-3}$). The largest POM concentrations occurred in the northwestern United States (Figure 3.1.2) where peak concentrations ranged from 5 to 12 $\mu g\ m^{-3}$, mainly in August and September due to biomass smoke influence. A strong seasonal pattern in POM was observed at these regions, with relatively low concentrations during winter months (<1 $\mu g\ m^{-3}$). This pattern was also observed for more-northerly regions in the southwestern United States (Figure 3.1.3), but the magnitude of the concentrations and degree of seasonality decreased farther south (e.g., Southern Arizona and West Texas).

The lowest IMPROVE regional monthly mean POM mass fraction occurred in the Virgin Islands region in July (0.040) and the CONUS region of Northern Great Plains in March (0.171), compared to the highest fraction (0.843) in the Northwest region in August. In the eastern United States, POM monthly mean contributions to RCFM were >0.5 during summer months in all of the CONUS regions and reached 0.765 in the Boundary Waters region in August and 0.713 in the Southeast region in April (Figure 3.1.4). Contributions during colder months were typically above 0.3. In the northwestern United States, POM contributions dominated the RCFM. Contributions were typically 0.4–0.6 and generally higher in summer (see Figure 3.1.5).

Contributions were often lowest for winter months, increased in summer, and remained high throughout the end of the year, such as in the Oregon/Northern California, Northwest, and Northern Rockies regions. In the southwestern United States, the magnitude and seasonality of POM contributions decreased (Figure 3.1.6). Contributions were still highest in summer and reached above 0.7, such as in the Sierra Nevada region, but farther south contributions decreased. For example, in the Southern Arizona region, monthly mean contributions were <0.5 year round, and peaked in both winter and summer. A similar pattern was observed in the Mogollon Plateau region. Contributions in the Hawaii region were quite low (<0.2).

3.3.2 CSN

The CSN POM regional monthly mean mass concentrations ranged from 0.33 $\mu g\ m^{-3}$ in the Hawaii region in July and 0.89 $\mu g\ m^{-3}$ in the CONUS region of North Dakota in February to 10.67 $\mu g\ m^{-3}$ in the Sacramento/Central Valley region in November. POM monthly mean concentrations in regions in the eastern United States ranged from 2 to 5 $\mu g\ m^{-3}$ and peaked during summer months in many regions farther north, such as the Chicago, Michigan/Great Lakes, Northeast, New York City, and Washington/Philadelphia Corridor regions (Figure 3.1.7). Toward the south, regions had less seasonal variability (e.g., Southeast region); however, magnitudes of POM were similar. Higher concentrations were observed in regions in the northwestern United States, likely associated with biomass smoke impacts. The Northwest, Portland, and North Dakota regions experienced monthly mean concentrations of 6–8 $\mu g\ m^{-3}$, especially during summer and fall months (Figure 3.1.8). The Alaska region had higher POM concentrations during cold months. In the southwestern United States, regions toward the north also experienced high POM concentrations during summer and fall, such as the Northwest Nevada, Sacramento/Central Valley, San Jose, and Front Range CO regions (Figure 3.1.9). Farther south, POM concentrations peaked during winter months, such as in the Albuquerque, Phoenix/Tucson, and West Texas regions. Relatively low monthly mean POM concentrations (<0.5 $\mu g\ m^{-3}$) were observed in the Hawaii region year round.

The maximum CSN monthly mean POM mass fraction of 0.776 occurred in the Alaska region in June and 0.755 in the CONUS region of Northwest Nevada in August. The minimum mass fraction of 0.120 occurred in the Hawaii region in January and in March for the North Dakota region (0.164). The monthly mean contribution of POM to RCFM in northern regions in the eastern United States were around 0.2–0.3 in cold months and over 0.5 in summer months (e.g., Chicago, Michigan/Great Lakes, and Northeast regions). For many regions farther south, the seasonal variability decreased and winter contributions were much higher. Year-round monthly mean contributions ranged from 0.4 to over 0.5, such as in the Southeast region (Figure 3.1.10). In the northwestern United States, POM contributions dominated RCFM with monthly mean contributions of 0.5 in winter months and over 0.7 in summer and fall months. The exception was the North Dakota region, with lower winter contributions due to the higher AN contributions (Figure 3.1.11). Contributions in the southwestern United States were also considerable in regions farther north, such as the Northwest Nevada region, where mass fractions over 0.7 occurred in summer months (Figure 3.1.12). In some regions large winter AN contributions led to more seasonal variability in POM contributions, with higher fractions during summer months and lower fractions in winter months, such as in the Sacramento/Central Valley, Utah, and Front Range CO regions. In regions farther south, such as the Phoenix/Tucson and San

Diego regions, contributions were higher during winter. In the Hawaii region, the monthly mean contributions from POM to RCFM were 0.2 or less year round.

3.4 $PM_{2.5}$ ELEMENTAL CARBON

3.4.1 IMPROVE

EC is emitted directly through emissions from incomplete combustion of fossil fuels or biomass. The maximum regional monthly mean EC mass concentration of 0.74 $\mu g\ m^{-3}$ occurred in the Oregon/Northern California region in August. The minimum regional monthly mean mass concentration occurred in the Hawaii region in August (0.010 $\mu g\ m^{-3}$) and in the CONUS region of Great Basin in February (0.03 $\mu g\ m^{-3}$). EC concentrations are difficult to discern on the bar charts because they are low relative to other aerosol species. In the eastern United States, concentrations rarely exceeded 0.3 $\mu g\ m^{-3}$ (Figure 3.1.1). Unlike other species, the monthly variability of EC was highly spatially variable. The Boundary Waters region peaked during summer months, Central Great Plains during spring months, Ohio River Valley during fall and winter months, Appalachia during fall months, and in the Southeast during spring and fall months. In the Virgin Islands region, monthly mean concentrations were below 0.1 $\mu g\ m^{-3}$ year round. The monthly mean seasonal and spatial variability suggests localized impacts of sources in regions in the eastern United States. In contrast, monthly mean concentrations in regions in the northwestern United States peaked in late summer and/or early fall for all of the regions (Figure 3.1.2). Concentrations were >0.5 $\mu g\ m^{-3}$ in the Hells Canyon, Northern Rockies, Northwest, and Oregon/Northern California regions in August or September, indicating the important role of biomass burning in the area. Lower monthly mean EC concentrations were also observed in regions in the southwestern United States (Figure 3.1.3) in summer, except in the Sierra Nevada region in August (~0.5 $\mu g\ m^{-3}$) and in the California Coast region in November (~0.5 $\mu g\ m^{-3}$). Farther south, concentrations peaked during winter months in the Southern Arizona region (~0.5 $\mu g\ m^{-3}$ in December). Otherwise, monthly mean concentrations in most regions rarely exceeded 0.2 $\mu g\ m^{-3}$. In the Hawaii region, monthly mean concentration were <0.04 $\mu g\ m^{-3}$ year round.

The minimum monthly mean contribution of EC to RCFM occurred in the Virgin Islands region (0.0016) in July and the CONUS region of the California Coast in June (0.0128). The maximum contribution occurred in the Southern Arizona region in December (0.093) and in the California Coast region in November (0.083). Contributions in regions in the eastern United States were nearly all near or below 0.05 (Figure 3.1.4). Contributions were similar in magnitude at regions in the northwestern United States, with the exception of the Northwest and Oregon/Northern California regions where contributions reached 0.07 during cold months (Figure 3.1.5). Relative contributions of EC were around 0.02-0.03 in many regions in the southwestern United States (Figure 3.1.6), with the exception of the California Coast region in November, Southern Arizona region in winter months, Mogollon Plateau region in fall and winter months, and the Central Rockies and Southern California regions, where contributions reached up to 0.09. Monthly mean contributions in the Hawaii region were near or <0.01 year round.

3.4.2 CSN

The CSN minimum regional monthly mean EC concentrations ranged from 0.06 $\mu g\ m^{-3}$ in the Hawaii region in July and 0.18 $\mu g\ m^{-3}$ in the CONUS North Dakota region in February to a maximum concentration of 2.01 $\mu g\ m^{-3}$ in the Las Vegas region in December. EC monthly mean concentrations in the eastern United States peaked between 0.5 and 1.0 $\mu g\ m^{-3}$ and were higher in regions such as the Ohio River Valley, Chicago, and New York City regions (Figure 3.1.7). Concentrations were generally low in regions farther south, with the exception of the Dallas and Southeast regions, where concentrations almost reached 1 $\mu g\ m^{-3}$ during cold months. Monthly mean concentrations were generally higher in regions in the northwestern United States than in the eastern United States. Concentrations reached over 1.0 $\mu g\ m^{-3}$ during fall and winter months, such as in the Puget Sound, Northwest, and Portland regions (Figure 3.1.8). Concentrations in the Alaska region were also near 2.0 $\mu g\ m^{-3}$ during winter months. In some southwestern regions, monthly mean concentrations also reached values over 1.0 $\mu g\ m^{-3}$, such as the Sacramento/Central Valley, San Diego, Los Angeles, Northwest Nevada, Phoenix/Tucson, and Albuquerque regions, often during late fall (Figure 3.1.9). EC monthly mean concentrations in the Hawaii region were relatively low, around 0.1 $\mu g\ m^{-3}$ or less.

CSN regional mean mass fractions ranged from 0.023 in the Hawaii region in April and 0.032 in the Dallas region in July to 0.160 in the Puget Sound region in December. Regional monthly mean EC mass fractions generally were <0.10 in many regions in the eastern United States (Figure 3.1.10), except the Chicago, Michigan/Great Lakes, Ohio River Valley, and Northeast regions. In the New York City region, EC monthly mean mass fractions were 0.1 or greater year round. Contributions from EC to RCFM were higher in the northwestern United States (Figure 3.1.11). The highest monthly mean EC mass fractions occurred in the Puget Sound region, where fractions over 0.1 occurred during all months. The Northwest and Portland regions experienced higher EC mass fractions during cold months, as did the Alaska region. EC mass fractions were generally lower (<0.1) for many regions in the southwestern United States (Figure 3.1.12). The exceptions occurred in the Northwest Nevada, Front Range CO, Las Vegas, Albuquerque and Phoenix/Tucson regions where mass fractions reached over 0.1, especially during cold months. In the Hawaii region, EC monthly mean mass fractions were <0.05 year round.

3.5 $PM_{2.5}$ FINE DUST MASS

3.5.1 IMPROVE

Sources of mineral dust in the atmosphere include entrainment from deserts, paved and unpaved roads, agricultural activity, construction, and fire. The seasonal and spatial variability of FD in the United States is influenced by local, regional, and long-range transport. A maximum 2016–2019 regional monthly mean IMPROVE FD mass concentration of 4.01 $\mu g\ m^{-3}$ was observed in August in the Virgin Islands region, a site known to have impacts from North African dust transport, especially during summer. The maximum CONUS region concentrations occurred in the Columbia River Gorge region in July (2.72 $\mu g\ m^{-3}$) and the Southern Arizona region in April (2.70 $\mu g\ m^{-3}$). The minimum concentration was observed in the Northwest region in December (0.03 $\mu g\ m^{-3}$) (see Figure 3.1.1). In the eastern United States, the highest FD concentration occurred during summer months, especially at regions farther south, such as the Southeast and Midsouth regions (>2.0 μg m^{-3}). However, increased concentrations during summer months also occurred in the East Coast, Appalachia, and Ohio River Valley regions. These regions are known to be influenced by the transport of North African FD during summer (Hand et al., 2017). Concentrations during winter months were relatively low (0.1–0.3 μg m^{-3}). Monthly mean FD concentrations in the Virgin Islands region were high from late spring through summer (3–4 μg m^{-3}). Monthly mean FD concentrations in the northwestern United States were highest in the Columbia River Gorge region in summer (Figure 3.1.2). Monthly mean concentrations in other regions were relatively low (<1 μg m^{-3}) but also peaked during summer months. Regional mean concentrations in the southwestern United States were highest (2–3 μg m^{-3}) for regions farther south (Figure 3.1.3) and peaked in spring and early summer months. Regions farther north, such as the Sierra Nevada and Great Basin regions, had higher concentrations during summer and fall months.

FD monthly mean contributions to RCFM ranged from 0.023 in the Northwest region in August to 0.543 in the Virgin Islands region in August, 0.513 in the Southern Arizona region in April, and 0.511 in the Columbia River Gorge region in June. In regions in the eastern United States, FD mass fractions were near 0.3 during July in the Midsouth and Southeast regions (Figure 3.1.4). In the Central Great Plains region, the mass fraction nearly reached 0.2 during July. In regions farther north, the monthly mean mass fractions were lower (<0.1). FD mass fractions in the Virgin Islands region were near 0.5 from late spring through early fall months. The largest mass fractions of FD in the northwestern United States occurred in the Columbia River Gorge region (Figure 3.1.5). In most other regions, the fractions were between 0.2 and 0.3 during late spring and early summer months. The highest FD fractions in the Northwest region occurred in April and May (~0.15), and the highest fraction in the Alaska region also occurred in April (~0.15). Spring maxima in FD mass fractions also occurred in regions in the southwestern United States (Figure 3.1.6), and the fractions were higher than in the northwestern U.S. regions. For most regions, the maximum fraction (~0.5) occurred in April. The exceptions were in the Sierra Nevada, California Coast, and Southern California regions, where the FD fractions were lower (<0.3) and exhibited less seasonal variability than other regions.

3.5.2 CSN

Regional monthly mean FD concentrations ranged from 0.09 μg m^{-3} in the Hawaii region in September and 0.15 μg m^{-3} in the North Dakota region in January to 4.75 μg m^{-3} in the Dallas region in July. Regions farther south in the eastern United States had higher FD concentrations in summer months, such as in the Dallas and East Texas/Gulf regions (4–5 μg m^{-3} in July) and the Midsouth and Florida regions (2–3 μg m^{-3} in July), likely influenced by long-range transport of dust from North Africa. Monthly mean concentrations in other regions ranged between 0.5 and 1.0 μg m^{-3} (Figure 3.1.7). In the northwestern United States, monthly mean concentrations were typically <0.5 μg m^{-3} in most regions year round. The exception was in the Northwest region, where concentrations reached over 1.0 μg m^{-3} in August, and the North Dakota region in June (Figure 3.1.8). In the Alaska region, the monthly mean FD concentrations reached ~0.5 μg m^{-3} in April and October. Relatively high concentrations were observed in many regions in the southwestern United States (Figure 3.1.9). In the Phoenix/Tucson region, monthly mean concentration were between 1 and 2 μg m^{-3} most of the year, and the West Texas region had monthly mean concentrations during spring months over 3 μg m^{-3}. Other regions (Front Range CO, Las Vegas, Albuquerque, and Utah) experienced monthly mean concentrations over 1 μg m^{-3} during most months. Monthly mean concentrations in the Sacramento/Central Valley region reached over 2 μg m^{-3} during fall months, and in the Los Angeles region monthly mean concentrations were over 1 μg m^{-3} during April and fall months. Monthly mean concentrations in the Hawaii region were <0.4 μg m^{-3} year round but peaked in March and April.

The maximum CSN urban FD mass fraction (0.492) occurred in the West Texas region in May, and the minimum mass fraction occurred in the Alaska region in January (0.018) and the Portland region in December (0.022). In the eastern United States, mass fractions of FD were highly seasonal and reached 0.4 in the East Texas/Gulf and Dallas regions in July and 0.34 in the Florida region in July. Mass fractions in regions farther north were typically <0.15 and for most regions ranged around 0.05–0.08 (Figure 3.1.10) with less monthly variability than regions farther south. Similar FD mass fractions were observed in regions in the northwestern United States (Figure 3.1.11). The exceptions occurred in the Northwest and North Dakota regions, where monthly mean FD fractions reached 0.25 in late spring and summer months. Mass fractions were higher for many regions in the southwestern United States (Figure 3.1.12). The Phoenix/Tucson, Albuquerque, and Las Vegas regions experienced mass fractions over 0.3 in spring, especially April. Mass fractions in the West Texas region ranged between 0.4 and 0.5 during spring months. Regions farther west had lower mass fractions, such as the San Jose and Los Angeles regions, where mass fractions were 0.1 or less year round. Monthly mean mass fractions in the Hawaii region were also <0.1 year round.

3.6 $PM_{2.5}$ SEA SALT MASS

3.6.1 IMPROVE

Estimates of sea salt (SS) discussed here are likely an underestimate, as chloride concentrations in the particle phase can be depleted by a gas–particle exchange of chloride to the atmosphere. The 2016–2019 regional monthly mean SS concentrations for the IMPROVE regions ranged from 0.007 μg m^{-3} in the Central Rocky Mountains region in November to 2.05 μg m^{-3} in the Virgin Islands region in January and 1.81 μg m^{-3} in the California Coast region in June. SS concentrations were visible on the monthly bar charts relative to other species for only a few regions. In the eastern United States, coastal regions such as the Northeast, East Coast, and Southeast regions had noticeable SS concentrations relative to other species (Figure 3.1.1). In the East Coast and Southeast regions, concentrations reached 0.7 μg m^{-3} in the late winter and spring months. Monthly mean SS concentrations near 0.2 μg m^{-3} occurred in the Boundary Water region in February, and concentrations of ~0.1 μg m^{-3} were observed in the Central Great Plains region. In the northwestern United States, monthly mean SS concentrations neared 0.2 μg m^{-3} in the Columbia River Gorge and Northwest regions in April (Figure 3.1.2), but in other regions, concentrations were typically <0.02 μg m^{-3}. In the Alaska region, monthly mean SS concentrations reached 0.7 μg m^{-3} in February.

IMPROVE SS mass fractions ranged from 0.0013 in the Northern Rockies region in August to 0.48 in the Alaska region in December and 0.45 in the Virgin Islands region in March. The maximum CONUS region mass fraction was 0.33 in the California Coast region in June.

Regions closest to the coast in the eastern United States had noticeable contributions of SS to RCFM, such as the Northeast, East Coast, and Southeast regions (Figure 3.1.4). Mass fractions in the East Coast and Northeast regions reached 0.15 in spring and fall months, while in the Southeast region, mass fractions near 0.15 were observed in spring months. In the Virgin Islands region, monthly mean mass fractions were higher year round, ranging from 0.16 to 0.45. In the northwestern United States, noticeable mass fractions were observed in the Northwest, Columbia River Gorge, and Oregon/Northern California regions. In the Northwest region, mass fractions were highest early in the year, just greater than 0.1. Similar mass fractions occurred in the Oregon/Northern California region. Much greater contributions of SS to RCFM occurred in the Alaska region, with fractions that ranged from 0.05 during summer months to near 0.5 during winter months (Figure 3.1.5). The California Coast region had the highest contributions of SS to RCFM of any region in the southwestern United States; mass fractions ranged from 0.08 in August to higher contributions through spring and early summer that peaked in June (Figure 3.1.6). The Southern California and Southern Arizona regions both experienced noticeable but low contributions during the first half of the year (~0.05).

3.6.2 CSN

Estimates of SS concentrations were derived from chlorine mass concentrations because CSN did not start reporting chloride until 2017. SS monthly mean concentrations ranged from ~zero in the North Dakota region and 0.0006 $\mu g\ m^{-3}$ in the Northwest region, both in April, to 1.03 $\mu g\ m^{-3}$ in the Hawaii region in December and 0.69 $\mu g\ m^{-3}$ in the San Jose region in June. SS concentrations were relatively low and difficult to discern on the bar charts corresponding to regions in the eastern United States (Figure 3.1.7), with the exception of the Florida and East Texas/Gulf regions. In the Florida region, SS monthly mean concentrations reached 0.65 $\mu g\ m^{-3}$ in February and 0.33 $\mu g\ m^{-3}$ in the East Texas/Gulf region in June. Monthly mean SS concentrations in the regions in the northwestern United States were quite low, generally around 0.1 $\mu g\ m^{-3}$ or less. In the Puget Sound region, SS concentrations reached 0.14 $\mu g\ m^{-3}$ and 0.11 $\mu g\ m^{-3}$ in the Portland region in December (Figure 3.1.8). In the inland Alaska region, monthly mean SS concentrations did not rise above 0.1 $\mu g\ m^{-3}$ year round. Regions in the southwestern United States were also associated with low SS concentrations. The San Jose region had some of the highest monthly mean concentrations that reached 0.69 $\mu g\ m^{-3}$ in June. SS in other regions rarely exceeded 0.15 $\mu g\ m^{-3}$ (Figure 3.1.9). The Hawaii region had higher monthly mean concentrations year round, ranging from 0.60 $\mu g\ m^{-3}$ in September to 1.03 $\mu g\ m^{-3}$ in December.

SS contributions to RCFM ranged from ~0 in the North Dakota and 0.0002 in the Northwest region in April to 0.38 in the Hawaii region in July and 0.12 in the Florida region in February. The Florida and East Texas/Gulf regions were the only regions in the eastern United States with discernable SS contributions (Figure 3.1.10). Similar low contributions were observed for regions in the northwestern United States (Figure 3.11). The Puget Sound and Oregon regions had the highest monthly mean contributions, near 0.01–0.02. In the southwestern United States, contributions in the San Jose region reached 0.1 in late spring and early summer months, but most other regions had contributions that were low (<0.05) (Figure 3.1.12). The Hawaii region had SS contributions that ranged from 0.22 in February to 0.38 in July.

3.7 $PM_{2.5}$ GRAVIMETRIC FINE MASS

3.7.1 IMPROVE

IMPROVE regional monthly mean FM concentrations ranged from 0.59 μg m^{-3} in the Great Basin region in January to 13.26 μg m^{-3} in the Oregon/Northern California region in August. Regional monthly mean FM concentrations mirrored the combined species concentrations on the bar charts shown in previous figures in this chapter. Regional monthly mean concentrations in regions in the eastern United States peaked during summer, around 6–8 μg m^{-3}, as was seen in Figure 3.1.1. The highest monthly mean concentrations occurred during summer in the Midsouth and Ohio River Valley regions. The Southeast region was influenced by biomass smoke during April, when POM concentrations increased over other months. In the northwestern United States, strong seasonal variability due to the impacts of biomass smoke and increased POM concentrations led to peaks in FM in the Northwest, Northern Rockies, Hells Canyon, and Oregon/Northern California regions, over 12 μg m^{-3} (Figure 3.1.2). Biomass smoke impacts also influenced FM concentrations in regions in the southwestern United States, such as the Sierra Nevada region in July and August, when FM was over 10 μg m^{-3} (Figure 3.1.3). Summer peaks in FM also occurred in many other regions but at lower concentrations (~6–8 μg m^{-3}). Seasonal variability in mean FM concentrations was lowest in the Southern Arizona region.

3.7.2 CSN

Monthly mean FM concentrations ranged from 3.02 μg m^{-3} in the Alaska region in May and 3.25 μg m^{-3} in the Northwest region in April to 23.27 μg m^{-3} in the Sacramento/Central Valley region in December. Monthly mean FM concentration peaked in both winter and summer in several northern regions in the eastern United States (Figure 3.1.7), such as the Northeast, New York City, Washington D.C./Philadelphia, and Ohio River Valley regions. Farther south, FM concentrations peaked in summer and were flatter during winter months. Monthly mean FM peaked in both summer and winter at regions in the northwestern United States and reached values near 10 μg m^{-3}, such as in the Northwest, Puget Sound, and Portland regions (Figure 3.1.8). Similar seasonal patterns in monthly mean FM occurred in regions in the southwestern United States (Figure 3.1.9). Winter and summer peaks were observed in the Sacramento/Central Valley, Northwest Nevada, Utah, and Front Range CO regions, for example. FM monthly mean concentrations in the West Texas region were relatively flat, while concentrations in the Phoenix/Tucson region peaked during winter. In the Los Angeles region, monthly mean concentrations for the first half of the year were relatively low and increased in June for the rest of the year.

3.8 COARSE MASS

CM is often assumed to be associated with mineral dust, although other studies have shown it also is associated with SS or biological particles and could include ionic species, such as sodium or nitrate, or organic carbon. Therefore, it may have seasonality similar to FD or could vary depending on sources and transport. IMPROVE 2016–2019 regional monthly mean CM concentrations ranged from 0.42 μg m^{-3} in the Northwest region in December to 28.38 μg m^{-3} in the Columbia River Gorge region in June. Regional monthly mean CM concentrations increased during late spring and early summer months in regions in the eastern United States, such as the

Boundary Waters, Ohio River Valley, East Coast, and Appalachia regions (Figure 3.8.1). Higher concentrations were observed in the East Coast and the Central Great Plains regions (~10 μg m^{-3}). Seasonal patterns in the Midsouth and Southeast regions were similar, with peaks near 8 μg m^{-3} in July. Monthly mean concentrations in the Virgin Islands region peaked in summer months (near 20 μg m^{-3}), likely associated with transport of North African dust and/or SS.

Regional monthly mean CM concentrations in regions in the northwestern United States were seasonally variable, with higher concentrations in summer and early fall months that dropped rapidly during winter months (Figure 3.8.2). Concentrations were highest in the Columbia River Gorge region, followed by the Northern Great Plains region. For most of the regions, the peak in monthly mean CM occurred in July or August and ranged around 5–8 μg m^{-3}. Concentrations were lowest in the Northwest region (peak ~3 μg m^{-3}), compared to monthly mean concentrations nearly ten times higher in the Columbia River Gorge region.

In the southwestern United States, the summer maxima observed in regions farther north (e.g., Sierra Nevada, Great Basin, Colorado Plateau, and Central Rockies regions) shifted toward the spring months for regions farther south (e.g., Southern Arizona, Mogollon Plateau, and West Texas regions; see Figure 3.8.3). The peaks in monthly mean CM during spring may be associated with dust source regions in the southwestern United States and Mexico and predominant meteorological conditions corresponding to dust episodes in those seasons. Some of the regions with the highest monthly mean CM concentrations (>10 μg m^{-3}) in the southwestern United States were located in California, including the California Coast, Southern California, and Sierra Nevada regions. The monthly mean CM concentrations in the Hawaii region were low (<2 μg m^{-3}) year round.

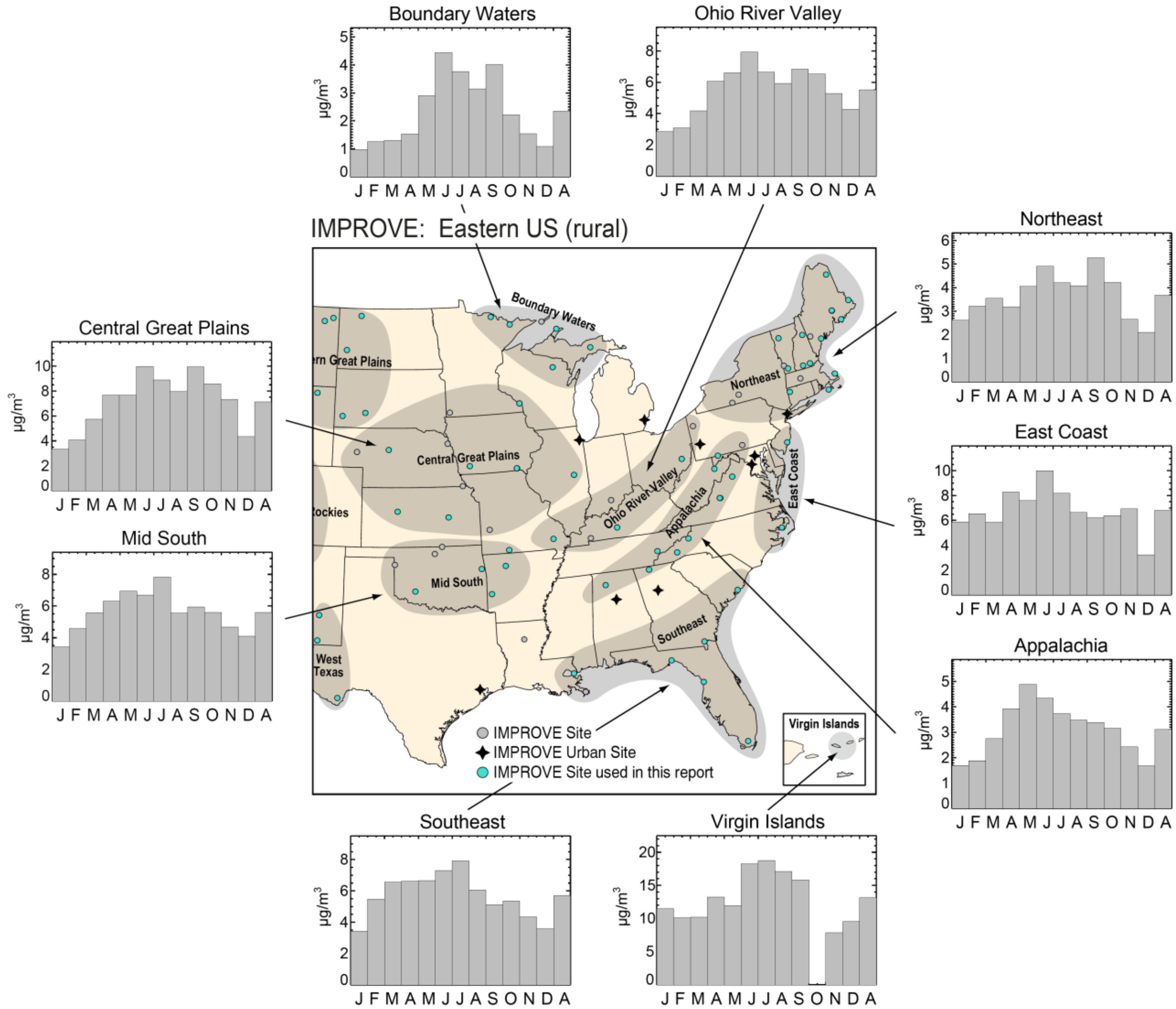

Figure 3.8.1. IMPROVE 2016–2019 regional monthly mean coarse mass (CM) concentrations (μg m^{-3}) for the eastern United States. Letters on the x-axis correspond to the month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as blue dots.

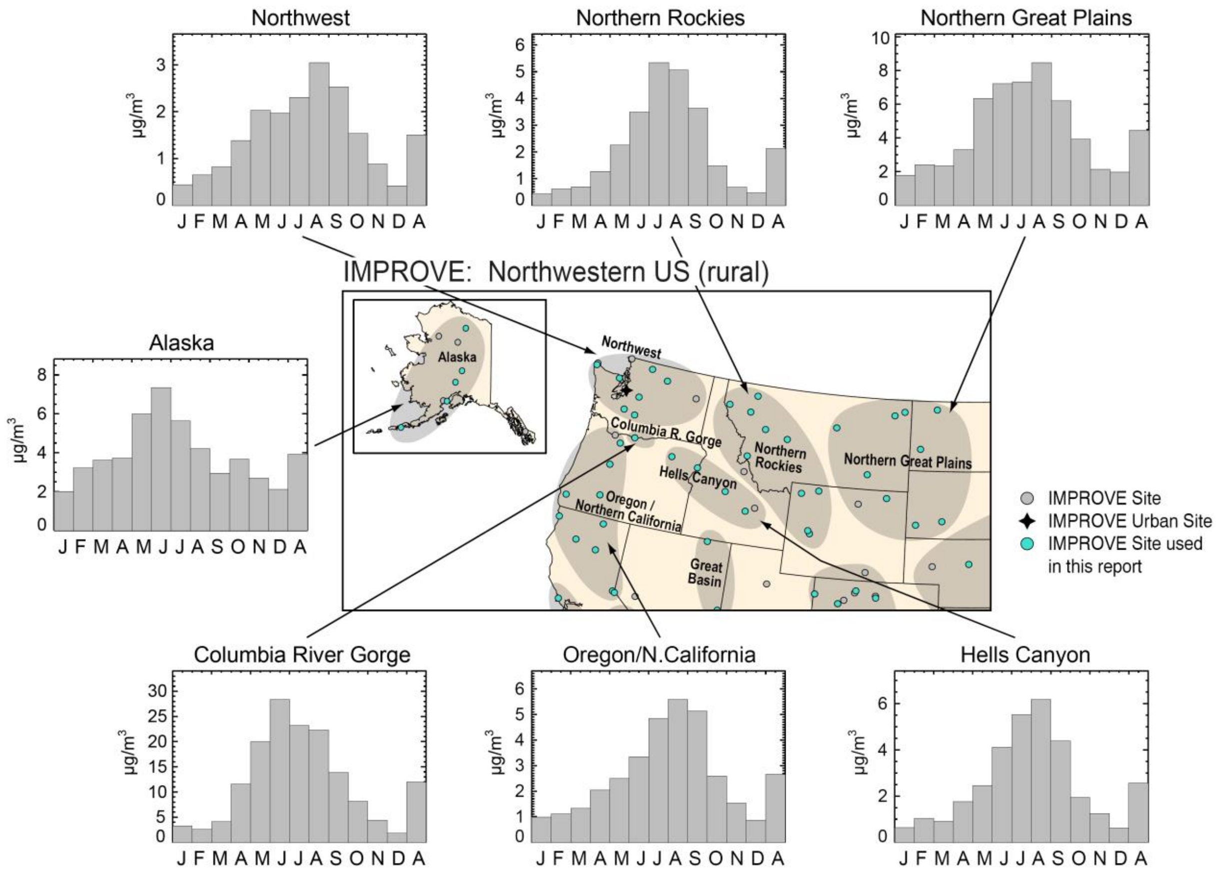

Figure 3.8.2. IMPROVE 2016–2019 regional monthly mean coarse mass (CM) concentrations (μg m^{-3}) for the northwestern United States. Letters on the x-axis correspond to the month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as orange dots.

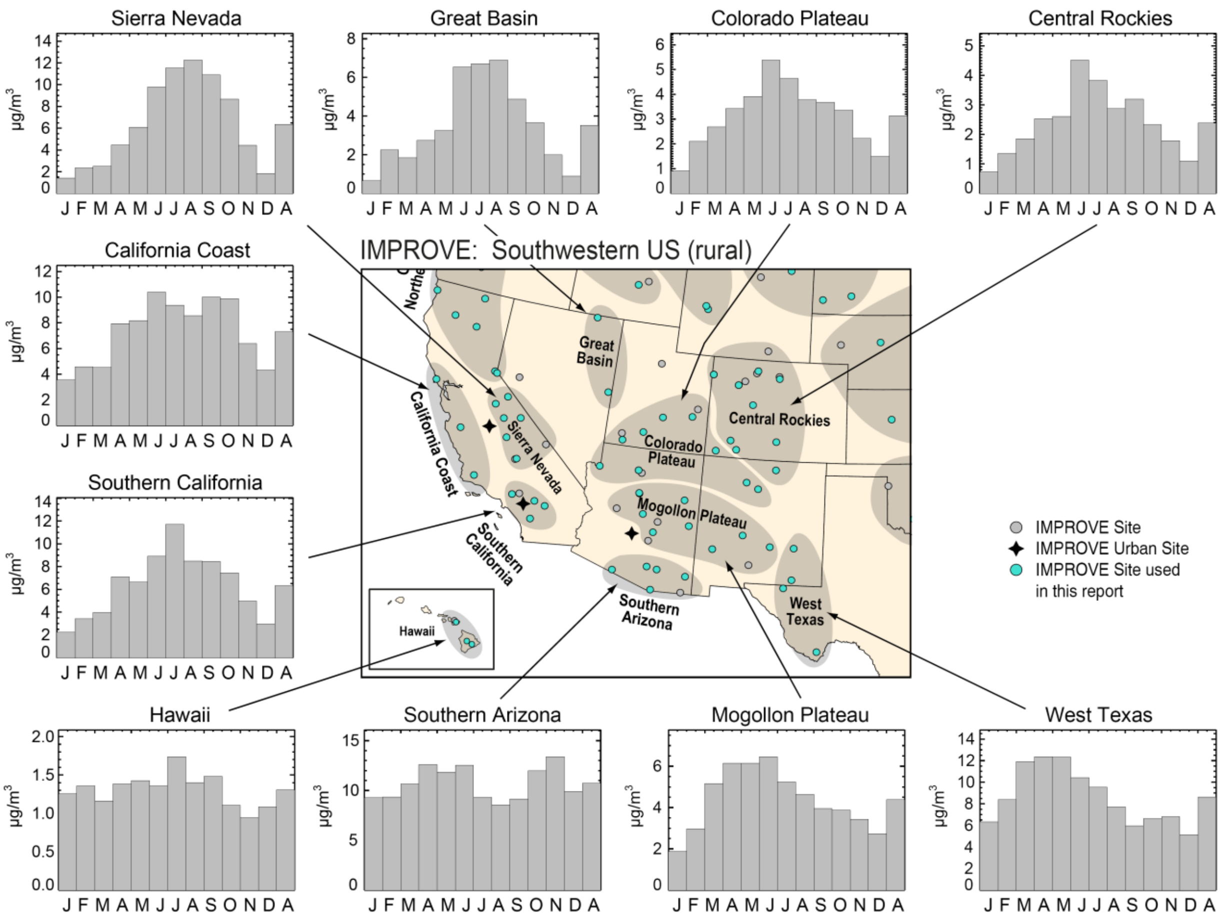

Figure 3.8.3. IMPROVE 2016–2019 regional monthly mean coarse mass (CM) concentrations (μg m^{-3}) for the southwestern United States. Letters on the x-axis correspond to the month and "A" corresponds to annual mean. Shaded areas in the map correspond to regions that include the sites used in the analysis, shown as orange dots.

3.9 DISCUSSION

The differences observed in the seasonal and spatial patterns in species concentrations for the rural regions of the IMPROVE network and the urban/suburban regions in the CSN network were indicative of the spatial extent of aerosol sources, atmospheric processes, regional transport, and sinks. For example, AS seasonal patterns and concentrations were similar for both the IMPROVE rural and CSN urban regions. In the eastern United States, monthly mean AS concentrations were similar in magnitude and had low monthly variability in both urban and rural regions. For nearly all urban and rural regions, monthly mean concentrations were near 2 μg m^{-3} or less and fractional contributions were <0.3. Concentrations in urban and rural regions in the northwestern United States were lower (<2 μg m^{-3}) than in regions in the eastern United States, likely due to lower emissions of SO_2. The variability of monthly mean AS concentrations was more pronounced in rural regions compared to urban regions in the northwestern United States, in part because of the large contributions from POM during summer. Some urban regions also exhibited this pattern. Contributions of AS to RCFM in northwestern U.S. regions were typically <0.2, lower than for eastern U.S. regions. In urban CSN regions in the southwestern United States, AS concentrations peaked in summer at many regions. Less monthly variability was seen in rural IMPROVE regions; however, similar magnitudes in concentration were observed.

Seasonal and spatial patterns in monthly mean AN concentrations were similar between urban and rural regions. For example, in the eastern United States, monthly mean concentrations were higher in regions farther north. Regions farther north were closer to areas with extensive agricultural activity, such as the Midwest United States. However, in urban regions AN concentrations were higher, although they peaked during winter months in both urban and rural regions, and often exceeded AS concentrations. Monthly variability and concentration magnitude decreased for regions farther south for both urban and rural regions. Contributions were a significant fraction of RCFM in urban and rural regions, especially during winter months in regions farther north. AN monthly mean concentrations were lower in regions in the northwestern United States, although concentrations in urban regions were still higher than in rural regions. Higher monthly mean concentrations were observed during winter months near areas of agricultural activity for both urban and rural regions. AN concentrations were higher than AS concentrations during winter months in many urban and rural regions in the northwestern United States. In the southwestern United States, higher urban mean AN concentrations were observed relative to rural regions, especially in California, Utah, and Colorado.

The strong summer maxima in POM concentrations in western rural regions suggested that wildfire activity was a major contributor to POM concentrations in rural areas, especially in the western and northwestern United States in summer. Biogenic secondary organic aerosol also could have contributed significantly to high summer POM concentrations. Urban regions experienced maxima in monthly mean POM concentrations during summer but also during winter months, which could be due to additional local sources and meteorological conditions. Summer maxima in regions in the northwestern United States were higher for rural regions, due largely to smoke impacts. In regions in the southwestern United States, both summer and winter maxima were common in urban regions, whereas most rural regions experienced maxima during summer. Seasonal and spatial variability in rural and urban regions was similar in the eastern United States, with higher concentrations during summer months. Less monthly variability was observed in urban regions farther south, which was not reflected at rural regions. POM monthly mean concentrations in eastern U.S. regions were typically higher than at rural regions. POM was the dominant contributor to RCFM at all areas of the United States. In the eastern United States, half of RCFM was composed of POM in both urban and rural regions, especially during summer months. These contributions were greater in both urban and rural regions in the northwestern United States; contributions over 0.7 were common. The contributions decreased for southwestern U.S. regions, but during summer, POM could dominate RCFM at both urban and rural regions, and in some urban regions, POM could be equally important during winter months.

Monthly mean EC concentrations were higher in urban regions across the United States. The urban regional monthly mean maxima were nearly three times higher than those in rural regions. In rural regions, EC seasonal and spatial patterns tended to follow those of POM, especially in northwestern U.S. regions where biomass smoke impacts were significant sources. Summer maxima in monthly mean EC reflected smoke contributions, but higher winter contributions were also observed, especially in urban regions, likely due to residential heating. Contributions to RCFM were also higher in urban regions across the United States.

FD concentrations were influenced by both local and long-range transport. While it is difficult to make direct comparisons between IMPROVE and CSN monthly mean FD concentrations due to existing biases, some similar spatial patterns were evident. The long-range transport of North African dust influenced both urban and rural regions in the eastern United States during summer in regions farther south. This influence was especially evident in the relative contribution of FD to RCFM. Monthly mean FD concentrations were higher near agricultural areas for both urban and rural regions, such as the Central Great Plains/Central U.S. and Northern Great Plains. The spring dust phenomenon in the southwestern United States also influenced both rural and urban regions. Contributions of FD to RCFM were significant during spring months (~0.5), suggesting both local and regional sources influenced RCFM across the southwestern United States.

While the seasons corresponding to maxima and minima for CM and FD concentrations agreed in some regions (e.g., in the northwestern United States and many regions in the southwestern United States), for many regions these seasons did not coincide. If FD was the main contributor to CM, their seasonality would be similar. It is possible and probably quite likely that the seasonality of CM was influenced by the variability of species other than mineral dust.

SS concentrations and fractional contributions were negligible in most urban and rural regions. Coastal regions (including regions on both the east and west coasts, including the Hawaii and Alaska regions) were the only regions to correspond to non-negligible impacts from SS on RCFM. SS corresponded to a high degree of seasonality.

FM concentrations were noticeably higher in urban regions than rural regions. The regional mean urban maximum was nearly twice that of rural maximum. The rural monthly mean maximum was likely due to the impact of biomass smoke, given its occurrence in the Oregon/Northern California region in August and the dominant role of POM. The maximum urban monthly mean FM concentration occurred in the Sacramento/Central Valley region in December due to POM and AN concentrations. For most urban and rural regions across the United States, depending on season, the highest FM concentrations occurred due to high contributions of POM and AN, highlighting their importance to the FM budget.

Tables with regional monthly mean concentrations listed as a function of species, month, and region are provided in Appendix 3.1 for IMPROVE and the CSN. Regional monthly mean mass fractions are listed in Appendix 3.2 for IMPROVE and the CSN.

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